P-117: O Films with Variable Tilt of Optical Axis for Display Application

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Abstract
The technology of positive O films with the tilt angle of optic axis continuously controlled in the range 0-90 º is proposed. It is based on the use of reactive mesogenes and alignment materials providing wide range control of pretilt angle. The developed method helps to optimize angular characteristics of LCD with O films.

1. Introduction
Liquid crystal displays (LCD) excel in low power consumption and operation voltage, high luminance and resolution, reach color gamut and excellent contrast at direct observation. However, oblique observation of LCD results in a loss of contrast, occurrence of grey-level inversion and color shifts. These undesired effects, resulting from the intrinsic birefringence of liquid crystal layers, lead to the angular dependence of light transmittance. There are known various techniques to improve the viewing-angle performance of LCD. The preferred by LCD industry technique uses supplementary birefringent films, which compensate undesirable phase retardation for the obliquely incident light.

The most popular for TN LCD compensation film is Fuji Film, which consists of discotic layer on a triacetate cellulose (TAC) substrate. It provides substantial improvement for the angular dependence of contrast and the grey level stability. At the same time, the Fudji film causes rather strong colour shift. According to Schadt et al. [1,2], optical phase retardation typical for Fudji film can be attained by using two positive O films with crossed optical axes. As result, TN LCDs compensated with a stack of two crossed positive O films, demonstrate viewing angle dependence of electrooptic contrast similar to those compensated with Fudji films. Simultaneously, color shift can be greatly improved. Both uniaxial O films [1] and spayed O films [2,3] can be used to realize this principle of compensation. In addition to TN LCD, combinations of O films offer great possibilities for compensation of LCD working in other modes [4].

The optimization of LCD with integrated O compensators, from the viewpoint of contrast angular dependence, grey-level stability and color shift, requests O films with certain thickness, optical axis tilt and birefringence. This requires technology of O films providing continuous variation of O film parameters. The present paper offers such technology. Same as in the studies mentioned above we make positive O films from reactive mesogenes (RM) lately proposed by Broer [5]. To control direction of RM alignment (direction of optic axis of O film) we use approach developed for conventional liquid crystals [6,7]. It consists in continuous change of LC pretilt angle from 0º to 90º by using mixture of two polyimides designed for planar and homeotropic alignment (polyimides p-PI and h-PI, respectively). The p-PI/h-PI layers are backed and unidirectionally rubbed to impart alignment function. The pretilt angle is continuously tuned with a change of ratio of PI concentrations. We demonstrate that this method suites well for reactive mesogenes allowing us to prepare O films with almost complete control of a tilt angle of optic axis in the range 0 – 90 º.

2. Experimental

2.1 Alignment substrates
We combined p-PI and h-PI precursors purchased from Japan Synthetic Rubber Co. providing excellent alignment and continuous pretilt angle control for conventional nematic liquid crystals [6,7]. The h-PI and p-PI give nominal LC pretilts of 88° and 5°, respectively. These polyimides were diluted in the standard solvent provided by JSR allowing them to mix. The concentration of h-PI precursor was varied from 0 to 100 % by weight to provide different pretilt angle of RM. The resulting solution was spin coated on glass slides to form the alignment film. The film was first preannealed at 90°C for 5 min and then annealed at 230°C for 90 min where most imidization took place. Finally, the PI layers were unidirectionally rubbed by the conventional rubbing machine.

2.2 RM films
The aligned RM films were obtained (1) by filling RM in a sandwich cell (confined films) and (2) by disposing RM on a single substrate (opened films).

In the <u>first case</u>, sandwich cells were assembled from two substrates so that the aligning PI films were from the inner side of the substrates and the rubbing directions were antiparallel. The gap between substrates was maintained by d=4.5 μm spacers. The cell was glued with Norland 65 photoadhesive by printing it on the edge of one substrate before the cell assembling. The glue was hardened by UV illumination (3 mW/cm^2, 365 nm, 1 min). The prepared cells were filled with a low-viscosity nematic RM UCL-011 from DIC. The filling was realized in low vacuum at 50^o C. After the filling, the cell was illuminated by UV light with the intensity 7 mW/cm^2 at 365 nm to solidify RM film.

In the <u>second case</u>, RM films were obtained by spin coating RM solution on the rubbed PI layer. In these experiments, along with RM UCL-011, we used two viscous nematic mixtures, UCL-017 from DIC and RMM256C from Merck, designed for planar alignment. All mixtures were dissolved in toluene at 30 wt %. The films were spin coated at 3000 rpm for 30 s and then kept at 60^o C for 1 min to remove residual solvent and improve RM alignment. The film thickness, detected by the interference method, was

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d=1.5-2 μm. For solidification, the films were illuminated by UV light (7 mW/cm^2, 365 nm) in argon atmosphere.

2.3 Film characterization

The alignment of RM layers was tested by viewing samples between a pair of polarizers and by sample observation in polarizing microscope.

The anisotropic properties were studied by the transmission null ellipsometry technique. In these experiments, the light beam from the He-Ne laser (λ=0.63 nm) passed through an optical system consisting of a fixed polarizer, an anisotropic sample, a quarter wave plate and a rotating analyzer and was registered with a photodiode. The polarizer axis formed angles of 45^o with the sample's slow axis and 0^o with the slow axis of the retardation plate. The analyzer rotation angle φ corresponding to the minimal transmittance of the laser beam was experimentally measured for different incidence angles of this beam on the sample, i.e., for different sample rotation angles α. The fitting of the measured φ vs α curves yielded retardation $(n^e\text{-}n^o)d$ and a tilt angle of the optical axis θ. The details of this method can be found in our previous papers [8,9]. The tilt angle of optic axis was also determined by a well-known crystal rotation method.

3. Results and discussion

3.1 Confined O films

Figure 1 shows set of samples, viewed between a pair of crossed polarizers, corresponding to different ratio of p-PI and h-PI precursors in the alignment film. There is evident excellent uniformity of RM films. One can also observe variation of the tilt angle of optic axis with a ratio of p-PI and h-PI concentrations.

Figure 2 demonstrates ellipsometric curves for three samples from the series shown in Fig. 1. The experimental curves (dots) are fitted well in frame of the model of uniaxial orientational structure with a tilted optical axis (O film model). This means that intrinsic liquid crystalline order of RM is preserved in the process of photopolymerization and so RM layer can be considered as a frozen liquid crystal. The fitting parameters corresponding to ellipsometry curves are summarized in Table 1. One can see that tilt angle of optic axis, accounted from the film surface, varies from 3^o to 89^o running from sample 1 to sample 4. They are confirmed with crystal rotation measurements (Table 1).

a

b

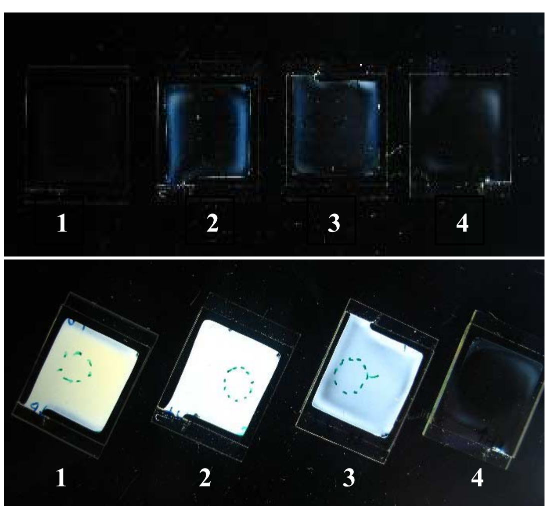

Figure 1. The cells filled with RM UCL-011 viewed between a pare of crossed polarizers: (a) the in-plane projection of optical axis is parallel to the polarization of incident light; (b) the in-plane projection of optical axis is tilted to the polarization of incidence light. The tilt angle of optic axis is 3^0, 33^0, 56^0 and 89^0 in cells 1, 2, 3 and 4.

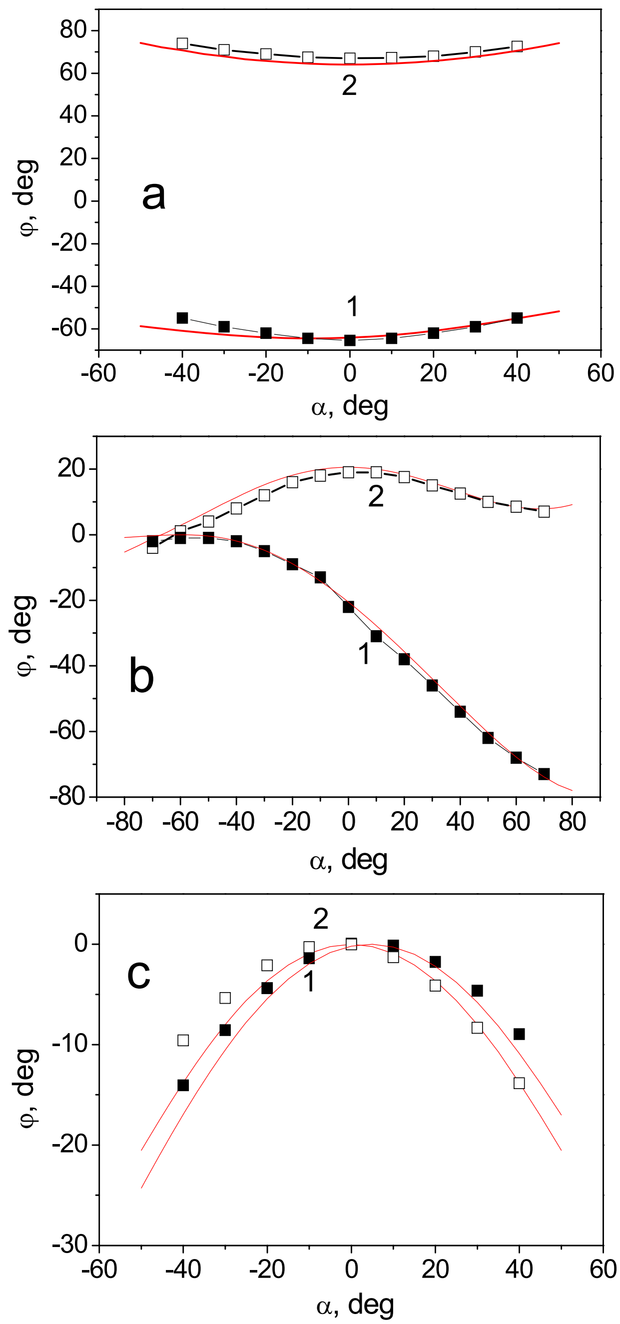

Figure 2. Measured (dots) and modeled (solid lines) analyser vs. light incidence angle curves for cells 1 (a), 2 (b) and 4 (c) from Fig. 1. The curves 1 and 2 correspond to two measuring positions of the cell, when in-plane projection of optic axis is orientated horizontally and vertically, respectively.

Table 1

Cell #	Concentration of h-PI, wt.%	Fitting parameters for ellipsometric curves		Tilt angle (crystal rotation), degree
		Tilt angle, degree	$(n_e-n_o)d$, nm	
1	0	3	225	3
2	10	35	225	33
3	15	55	225	56
4	20	65	225	64
5	100	89	225	89

3.2 Opened O films

Figure 3 shows that spin coated RM films are of good alignment quality. No considerable alignment defects are detected on the microscopic level as well. The difference in a brightness of the films is caused by the difference in an optic axis tilt.

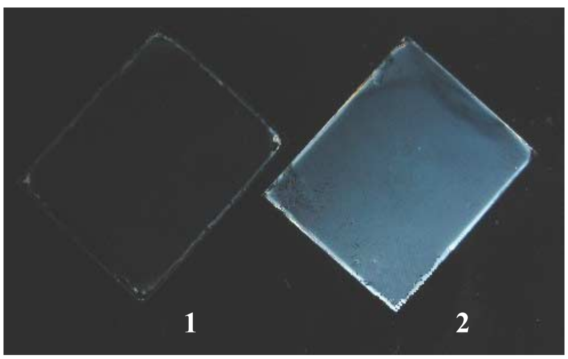

Figure 3. The films of UCL-011 (1) and UCL-017 (2) coated over rubbed p-PI/h-PI (4:1) layers viewed between a pare of crossed polarizers. The in-plane projection of optical axis is tilted to the polarization of incidence light.

Table 2

Cell #	Concentration of h-PI, wt.%	RM	Concentration of h-PI, wt.%	Fitting parameters for ellipsometric curves	
				Tilt angle, degree	$(n_e-n_o)d$, nm
1	20	UCL-011	20	70	85
2	20	UCL-017	20	30	78
3	20	RMM256C	20	30	80

The ellipsometric curves obtained for film 1 and 2 are shown in Fig. 4 a and Fig. 4 b, respectively. The solid lines correspond to fitting in frame of O film model. The corresponding fitting data for these films, as well as for the RMM256C film, are given in Table 2. There is evident that optic axis tilt for the UCL-011 film is much higher than for the films of UCL-017 and RMM256C

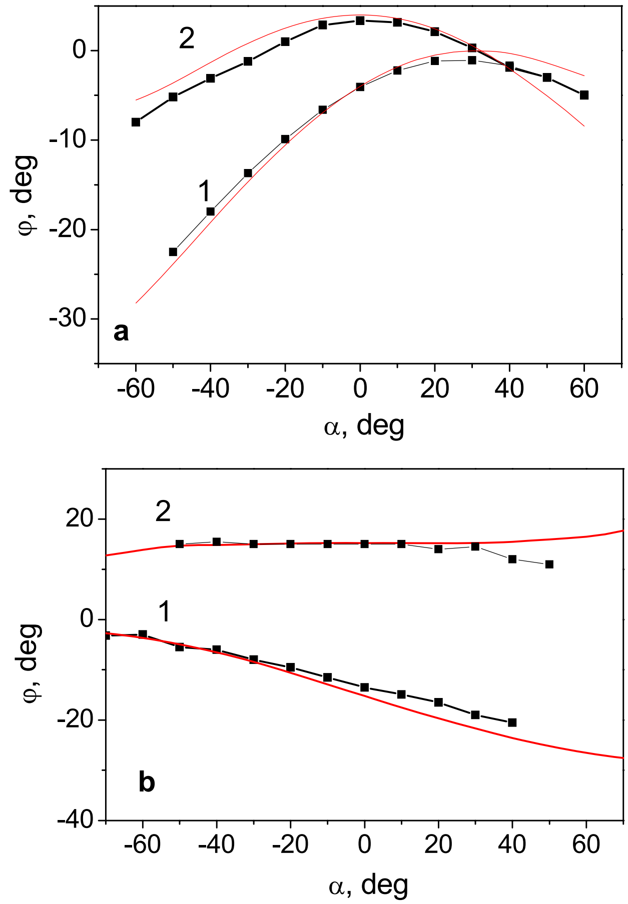

Figure 4. Measured (dots) and modeled (solid lines) analyser vs. light incidence angle curves for cells 1 (a) and 2 (b) presented in Fig. 3. The curves 1 and 2 correspond to two measuring positions of the cell, when in-plane projection of optic axis is orientated horizontally and vertically, respectively.

planar mixtures, which usually contain planarization agents. Furthermore, tilt angle of UCL-011 film is even higher than that of the film constrained between two aligning substrates (Table 1). These data can be explained by nonuniform alignment of RM molecules across the open films. It is reasonably to assume that, in contrast to the confined UCL-011 films having uniaxial structure (Fig. 5 a), opened RM films have splayed structure. This agrees with an insufficiently good fitting of ellipsometric curves measured for these films in a frame of uniaxial model (Fig. 4). One can suppose that molecules on the top of the film of UCL-011 mixture having no planarization additives aligned normally (or almost normally), whereas molecules of UCL-017 and RMM256C planar mixtures align planarly (or almost planarly) on the border with an air. This means that UCL-011 film has a structure shown in Fig. 5 b, whereas UCL-017 and RMM256C films have the structure presented in Fig. 5 c. Thus, along with classical uniaxial O film, splayed O films are realized. The averaged optic axis tilt in these films can be controlled with a ratio of h-PI and p-PI alignment materials, same as in case of confined films considered above.

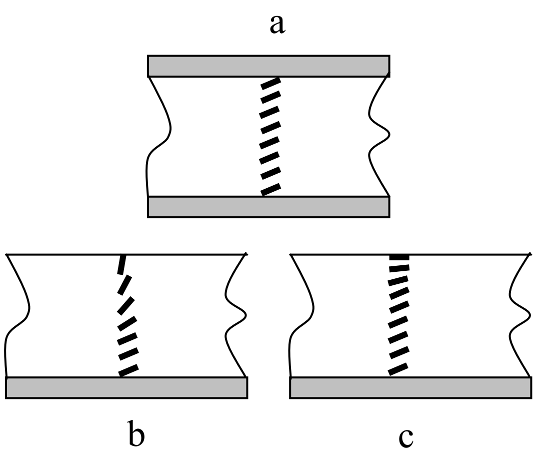

Figure 5. Structures of realized O films.

4. Conclusions

We attained RM alignment with pretilt angle controllable in, practically, full range from 0^o to 90^o. Optically these RM layers act as positive O films, which transform to positive A film and positive C film at pretilt angles 0^o and 90^o, respectively. The structure of RM layer is preserved in a solidification process. This allowed us to obtain solid O films with controllable tilt angle of optic axis. The prepared O films are confined between two aligning substrates or coated on one aligning substrate. In the first case, RM alignment is uniform along the film normal, while in the second case splayed structure is formed, which depends on the content of RM mixture. In spite of the use of glass substrates in our experiments, the approach is applicable to plastic substrates. Moreover, RM film can be extracted to use separately from the alignment substrates. We believe that developed method will be useful for optimization of LCD angular characteristics with O compensation films.

5. Acknowledgements

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6. References

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